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Evaluating the Role of Energy Storage Systems in Vietnam's Renewable Energy Integration

Le Thi Thuy Hang[1],*, Cu Thi Thanh Huyen[1], Le Cong Thinh[1]

Abstract

Energy transition is taking place around the world due to the strong penetration of renewable energy sources in modern power systems. However, the most important disadvantage of these power sources is their instability. As a result, power systems are facing major challenges in transmission and distribution with unpredictable daily and seasonal fluctuations to meet the demands of human activities. Energy storage is being considered as one of the potential solutions to address these challenges, whereby energy is stored and converted to electrical energy when needed. There are many types of energy storage technology with different applications in modern energy systems. This paper provides an up-to-date review of these storage technologies and energy storage systems in Vietnam's power system today. Finally, there are a few perspectives on the opportunities and challenges of these storage systems in Vietnam power systems today.

Keywords: Energy storage, renewable energy, power system, Vietnam, fossil fuels

INTRODUCTION

Nowadays, renewable energy sources (RES) are developing rapidly and strongly on the entire world [1, 2]. By 2021, the installed capacity of renewable power is more than 256 GW, covering around 29% of global electricity mix. Promoting the development of RES is a necessary orientation in the current context of severe global climate change and the requirement for energy security and sustainable development [3–6]. These issues are also mentioned in the Kyoto Protocol [4] as well as in the United Nations Framework Convention on Climate Change at COP21 and COP26 [5, 6].

However, the high penetration of these sources could cause local supply-demand imbalance due to their variable characteristics. Several countries have made efforts to increase the flexibility of power systems in line with the growing share of solar photovoltaic (PV) and wind power. Many interventions have been introduced to maintain the stability and reliability of the grid, including increasing grid flexibility, expanding and interconnecting transmission infrastructure, curtailing generating capacity, and/or developing energy storage facilities. Moreover, governments also introduce flexible policies, including time-of-use pricing, incentives, and penalties for electricity use.

The grid flexibility is reflected in the ability to respond to changes in electricity supply and demand [7–10]. On the supply side, adding flexible generators to the grid such as natural gas generators or hydropower allows responding quickly and efficiently to changes in the supply side integrating large shares of renewable energy. On the demand side, the addition of intermittent loads such as

***Author for Correspondence**
Le Thi Thuy Hang
E-mail: lethithuyhang@istee.vast.vn

[1]Research Scholar, Institute of Energy and Environment Science Technology, Vietnam Academy of Science and Technology, Vietnam

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hydrogen fuel production, desalination or other power-to-X technologies allows taking advantage of excess RES output at oversupply time. However, the use of natural gas or hydropower may impact negatively on the environment, and the intermittent loads require the advanced control technologies. Expanding the transmission infrastructure is also one of the solutions to ensure the flexibility and reliability of the grid [10]. This measure allows reducing the geographical risks when potential RES areas and load centers are far away.

Unlike fossil fuel generators that can flexibly adjust power output through controlling fuel input, unused electricity from RES would be lost forever, and that is a waste of these sources [11, 12]. Oversupply and curtailment are largely due to a mismatch between supply from RES and local demand. This mismatch can occur during different times of a day and between seasons of the year when the peak time of solar power output does not match the load demand at that time. In addition, the mismatch can occur when regions with high solar potential are located far from the load centers and the transmission capacity of the two regions is limited. Due to this reason, in 2018, the curtailment of solar PV output in China was about 9.6%, reaching up to 16% in the solar-rich Northwest region. In Chile, the curtailment of solar PV output was about 6% due to the limited infrastructure of the transmission line. In Germany, the application of advanced control technologies right at the distributed PV systems has allowed to limit PV curtailment of below 1% and increase the stability of the grid [13]. In the United States, the curtailment in solar PV varies from state to state [13]. In states with good infrastructure, the curtailment was less than 5%, like California and Arizona, but in states with poor transmission, the curtailment can be as high as 10%, like Texas or Hawaii.

The curtailment of RES electricity, especially solar and wind power, could cause economic, technical, and social losses [10, 14, 15]. The first is the loss of energy due to not using all the generated electricity. In addition, this curtailment also represents a missed opportunity in reducing emissions, as well as reducing economics and hindering the implementation of future renewable power projects.

Energy storage in utility networks is becoming increasingly important and widespread under a wide integration of RES (Figure 1) [16, 17]. Services and options of energy storage systems also vary widely in all subsystems of production, transmission, substation, distribution, and end-consumer according to the type of technology used (Figures 2 and 3) [2, 17, 18].

Energy storage systems could absorb excess power from wind and solar energy sources and then use this power to make up for energy shortfalls during peak hours. This also means that energy storage turns to be essential to balance supply and demand as well as increase the flexibility and stability of the grid.

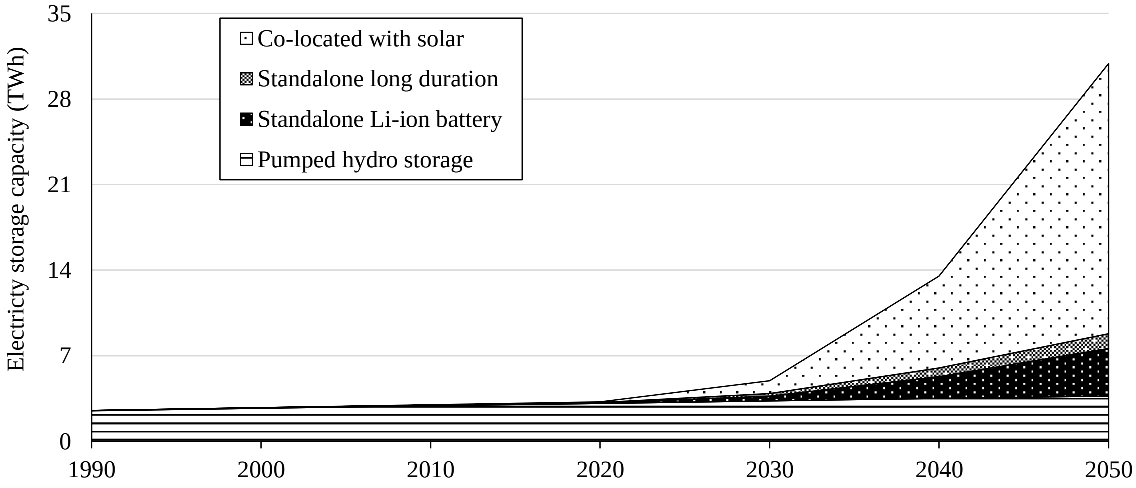

Figure 1. Global utility-scale electricity storage capacity today and tomorrow [16, 17].

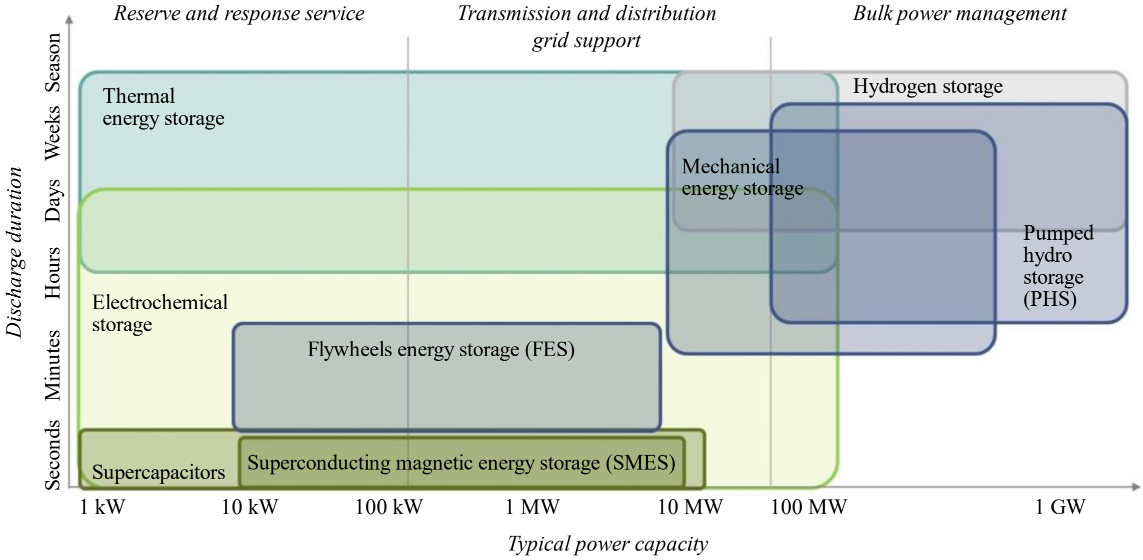

Figure 2. Technologies and applications of energy storage today [2, 17, 18].

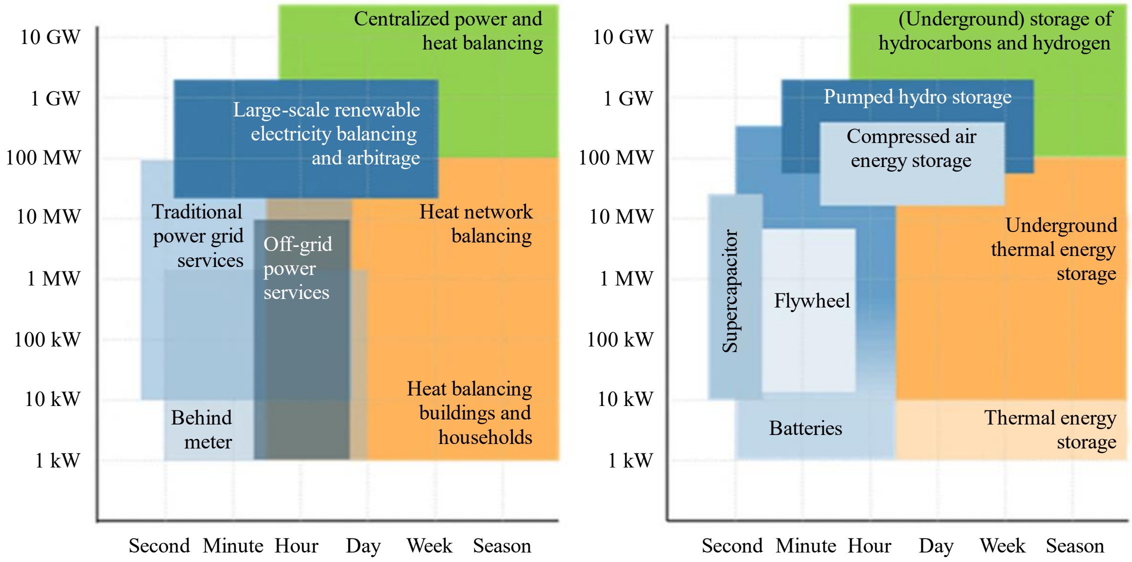

Figure 3. Services and options of energy storage technologies [2, 17, 18].

Moreover, energy storage also contributes to reducing congestion in the transmission system, maintaining voltage and frequency stability, compensating for generating set failures, and keeping a real-time balance between generation and consumption [16, 17, 19].

CURRENT ENERGY STORAGE TECHNOLOGIES

There are many energy storage technologies used in power systems today, including thermal storage technology, flywheel storage technology, compressed air storage technology, electrochemical storage technology, pumped hydro storage (PHS) technology.

Thermal Storage Technology

Thermal storage technology is a storage technology that involves thermal energy, either “hot” or “cold” [18, 20]. The storage medium may be a natural or human-made structure and must prevent heat exchange with the surrounding environment. There are some main ways to store thermal energy, which are sensible, latent and thermochemical. Storing heat in the sensible way is to raise the temperature of the medium, whilst latent heat storage involves changing the phase of the storage material, including solid-gas, liquid-gas, and solid-solid. The storage capacity of these technologies could be up to hours, days, even months depending on the capacity of the storage system used.

Thermochemical storage technology allows the storage/release of thermal energy through chemical reactions under three stages: endothermic dissociation, storage of reaction products and finally exothermic reactions [18, 20]. This technology has higher storage density and lower energy loss than sensible and latent storage technologies, and is therefore more compact in size and has good potential for long-term storage [21–23].

Thermal storage technologies are one of the solutions to increase the flexibility of energy systems [21, 24, 25]. This technology could contribute in reducing peak electricity demand, softening fluctuations in renewable power sources, and providing additional services for distribution networks, micro power systems, or multi-energy systems.

Flywheel Storage Technology

Flywheel storage technology is storage in the form of kinetic energy, where the flywheel acts as a motor or a generator depending on the input/output mode of the energy stored [18, 20, 26]. The popular device used for flywheels is a permanent magnet generator due to its high efficiency and power density, and low rotor loss [27, 28]. Besides high energy and power density, flywheel storage systems also have advantages such as long working life, a high life cycle (up to tens of thousands), and low environmental impact [26, 29]. However, this technology has a lower energy density than batteries and supercapacitors.

Flywheel storage technology could be applied in the electricity sector at many scales from small to large [26, 29]. Besides energy storage, the best applications of flywheel technology are in systems where high power is required for short time (up to 100 kW/s), whilst common applications are frequency and voltage regulation, load balancing, hybrid and electric vehicles, etc.

Compressed Air Storage Technology

Compressed air storage technology is realized when air is compressed and stored in large-scale storage mediums, which are usually located underground [18, 20]. These mediums could be natural caves or human-made steel tanks, and the air inside them is highly pressurized to generate electricity by being released to turbines.

The advantage of this technology is that it is flexible in using energy (discharge time of hours to days), and therefore easily adaptable to grids with integrated renewable energy [18, 20, 30]. However, the cycle efficiency of this technology shows lower than pump-storage hydropower and electrochemical storage technology. Geological restrictions and challenges also impact the diffusion of this technology.

Electrochemical Storage Technology

Typical electrochemical storage technologies today can be found in batteries and capacitors [18, 20]. Basically, this technology converts chemical energy directly to electrical energy. Batteries are classified as electrochemical storage technologies with high energy density, typically including lithium-ion (Li-ion), sodium-sulfur (NaS), nickel-cadmium (NiCd), lead acid (Pb-acid), etc. Among these batteries, lithium batteries are increasingly popular and play an important role in energy storage today because of the highest storage capacity, while sodium batteries are the cheapest due to the wide availability and low cost of sodium. Capacitors with similar technology are commonly used to store and supply electrical energy, including electrostatic capacitors, electrolytic capacitors, and electrochemical capacitors, of which the electrochemical capacitor has the largest capacitance per unit volume, also known as ultra-capacitor (UC). Looking at the storage capacity [31, 32], the battery may store up to 30 times more energy than the UC per unit mass, whilst the UC could cycle more than the battery and provide power thousands of times more than batteries of the same mass.

Electrochemical storage technology is a recently developed method of electrical energy storage and is mainly applied in small systems such as in transportation systems, and portable/backup power sources [20, 33, 34]. Moreover, batteries and supercapacitors could be studied and developed for utility applications such as at substations to improve reliability here, or at a grid scale with rapid response to changes in load or input like RES [34–38].

Pumped-Storage Hydropower Technology

The dominant storage technology in today's power system is the pumped hydro storage (PHS) technology, which accounts for more than 90% of total global energy storage capacity [16, 17, 19]. The principle of PHS is to store electrical energy by utilizing the potential energy of water. The major drawback of this technology, though, is that it's geographically limited, so PHS could only add up slightly for energy storage over the next decades. Besides this PHS technology, electrochemical technology, represented by Li-ion batteries, is also the popular storage technology today for utility-scale storage, electric vehicles, and information-communication technologies. However, high production costs coupled with supply chain shortages during the pandemic and the current energy crisis have negatively impacted the proliferation of this type of technology.

By 2020, global PHS capacity reached 160 GW, the top countries being as China, Australia, India, Scotland and Turkey [2]. Most of these projects are developed with the aim of supporting RES integration, providing power and grid services to utilities. Besides, the PHS can support increased flexibility of the grid and reduced emissions of the supply system. The PHS projects of 500 MW Dungowan and 400 MW Big-T in Australia were designed to support RES integration and provide grid support services. The 440 MW Cruachan PHS in United Kingdom was designed to supply synchronous compensation. The 1.2 GW PHS projects in Pinnapuram and Saundatti in India were designed to support the 4 GW wind and solar power plants.

ENERGY STORAGE IN VIETNAM POWER SYSTEMS

In Vietnam, today, the use of storage systems for renewable power is mostly used for small islanded networks disconnected from the national grid, while for the grid-connected systems, Vietnam still has no integrated storage applications in place.

In fact, energy storage in Vietnam have been concerned and implemented since the 1970s [39, 40]. Before the 2000s, the main types of energy storage in Vietnam networks were batteries and accumulators, also known as electrochemical storage technology. This technology has been used in isolated power systems using local power sources such as wind and solar power in Vietnam (Figures 4–7) [39, 40]. These systems were often installed to serve the lighting and daily activities of residents in areas without the national grid (Table 1) [39, 40]. The models in Figures 4 and 5 were most commonly used due to its simplicity in operation and maintenance, while other models are often used for larger load groups. The southern region was the first place to apply these systems, while the northern was slower but develops quite quickly. Most of these projects were funded by the government and non-profit organizations at home and abroad.

Since the 2000s, besides electrochemical storage technology, PHS technology has also attracted the attention of the government due to its benefits of meeting grid services. Until recent years, PHS technology has shown its necessity in the context of the solar power boom in the country [41–43], and as a result, the rapid deployment of Bac Ai PHS system in Ninh Thuan.

Obviously, most of solar PV plants in Vietnam are concentrated mainly in the South Central area [2, 43]. Specifically, the total installed capacity of new solar PV plants in the South Central was 68% in 2019 and 70% in 2020. The 2020 installed capacity of new solar PV plants is mainly located in the Ninh Thuan province due to the special incentives of the policy mechanism. Meanwhile, the load centers are located in the big cities like Hanoi, Ho Chi Minh City, or Da Nang [44, 45]. Therefore, the power from

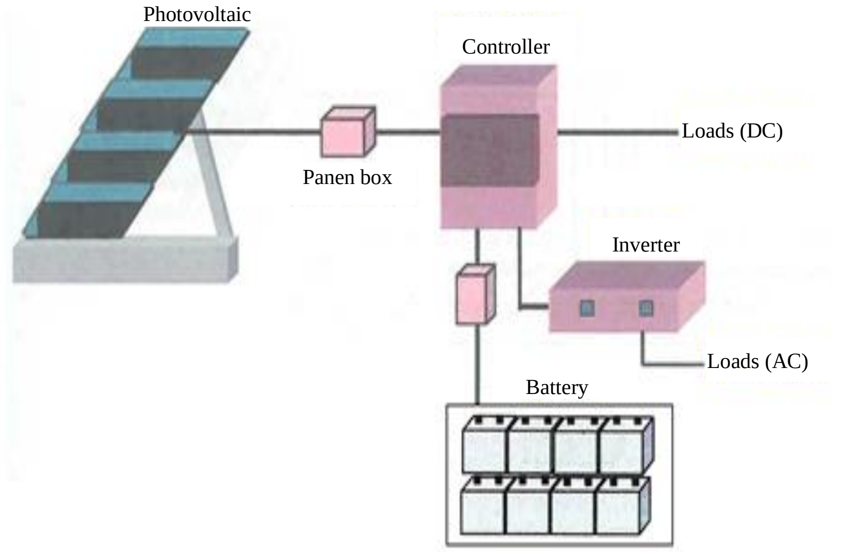

Figure 4. Model of power supply system using photovoltaic [39, 40].

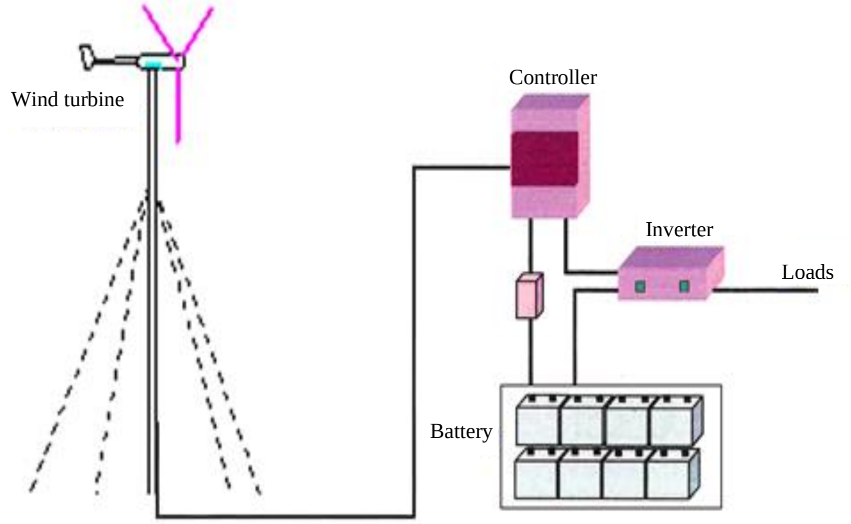

Figure 5. Model of power supply system using wind turbine [39, 40].

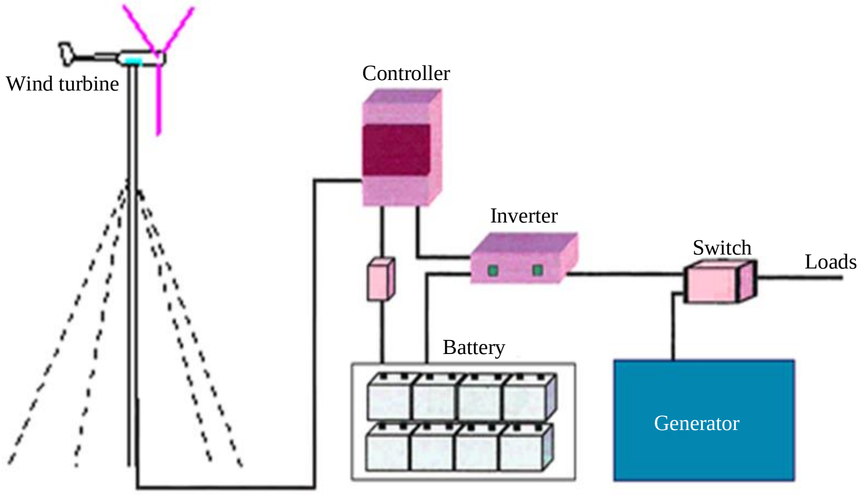

Figure 6. Model of power supply system using wind turbine and diesel [39, 40].

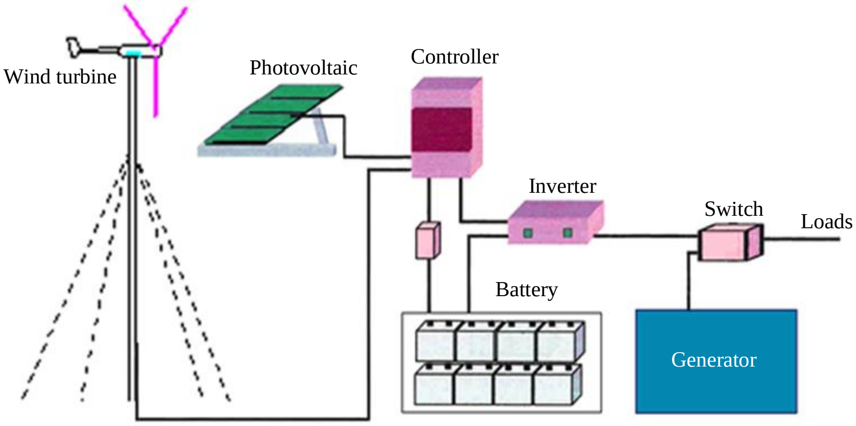

Figure 7. Model of power supply system using energy mix [39, 40].

Table 1. Applications of power systems using energy storage till 2000 [39, 40].

Application	Capacity (W)	Quantity	Start year	Installed area
Photovoltaic	50–1000	~5000	1970s	Northeastern islands, Northwest mountainous areas, Highlands, Mekong Delta rural areas
Wind turbine	100–200	~1000	1990s	Central coastal
Hybrid systems	2000–30000	2	1999	Nam Dinh, Kon Tum

the Ninh Thuan region, such as other highly concentrated areas of solar PV plants, is transferred to nearby high-load areas. However, the transmission of power between these areas in Vietnam encountered many issues due to the weakness of the transmission grid [46, 47].

Applications of Power Systems

Applications of power systems using energy storage up to year 20th century is shown in Table 1.

OPPORTUNITIES AND CHALLENGES FOR VIETNAM ENERGY STORAGE

Clearly, energy storage has received attention from the Vietnamese government since the 1970s [39, 40]. However, most of these storage systems are small-scale and in electrochemical forms such as batteries and capacitors. The long-term indifference of the Vietnamese government has caused storage systems to play only a faint role in power systems and only be present in small-scale independent power systems.

In recent years, the explosion of wind and solar energy has created a huge need for the operational security of power systems nationwide. This requires appropriate solutions for releasing excess renewable energy sources while ensuring the stability and reliability of power networks. Energy storage is one such solution in RES-based power systems today.

The Vietnamese government is paying attention to large-scale energy storage systems, focusing on PHS technology. In addition to storing excess energy from RES, the development of PHS is also driven by the sharp increase in peak demand for power and the wide gap between off-peak and peak demand [48, 49]. Three solutions of power source combination are considered to assess peak support needs and whether that need is best met through PHS or other alternatives, including: the optimal mix of sources including coal power plants, gas power plants, and RES power plants without the PHS plants; the optimal mix of sources including coal power plants, gas power plants, and RES power plants combined with the PHS plants; and the optimal mix of sources including coal power plants, gas power plants, and RES power plants plus single gas turbine units.

In fact, energy storage is covered in the documents of National Power and Energy Planning, where PHS technology is particularly interested in grids with high renewable energy penetration [41, 42] (Figures 8 and 9). The Government of Vietnam is determined to promote the development of RES and

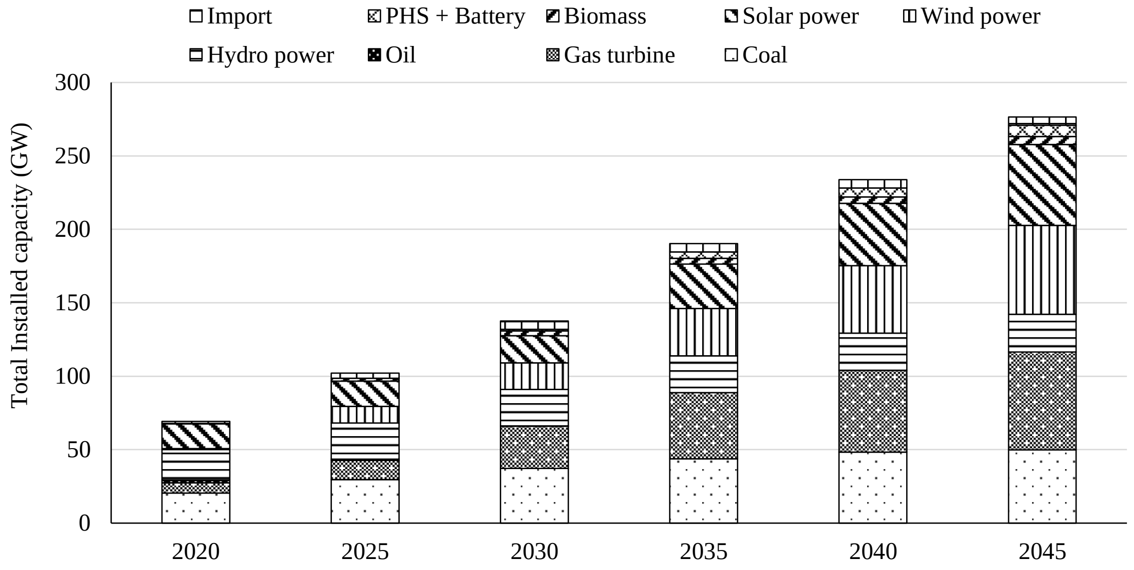

Figure 8. Planned capacity of power sources by 2045 in Vietnam [41, 42].

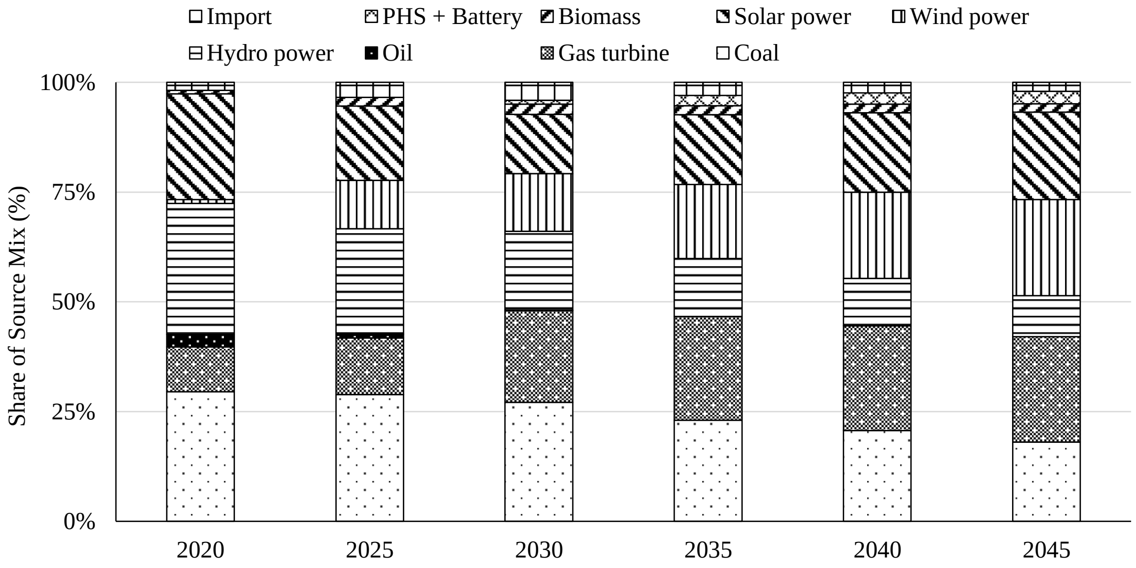

Figure 9. Planned structure of power sources by 2045 in Vietnam [41, 42].

energy storage facilities in order to reduce dependence on traditional and imported fuels. However, until now, there are not many documents detailing the implementation of these development plans and there is still a lack of other accompanying incentive policies for the research and deployment of energy storage facilities. The promulgation of these inconsistent documents may negatively impact the current research, application, and deployment of domestic energy storage types. These actions also reduce the confidence of domestic and foreign investors in the energy storage sector, and therefore in renewable energy investment.

Moreover, it can be seen that the Vietnamese Government seems to only be interested in two storage technologies: electrochemical technology and PHS technology. Almost all issued documents only mention the criteria for these two types of storage technology. This is said to create opportunities for these two storage technologies but poses challenges for other storage technologies. Policy constraints could have a major impact on the development and expansion of RES sources in energy networks because they depend on the diversification potential of storage systems.

CONCLUSIONS

In today's context of rapidly increasing demand for renewable energy, the application of energy storage systems in utilities is becoming increasingly important to ensure the operational security of power systems. These storage systems could be deployed at any subsystem in the power system, including generation, transmission, substations, distribution, and end consumers. The combination of storage systems and renewable energy in networks enables increased penetration of renewable energy, improving overall performance and increasing grid flexibility.

In order to achieve the goal of reducing net carbon emissions to zero by 2050, Vietnam should promote research and development of energy storage systems on both large and small scales for the short- and long-term roadmap. In particular, it is necessary to flexibly apply storage technologies to support the stable operation of existing energy systems and to push the expansion of various renewable sources. In addition, the Vietnamese Government needs to develop a clear roadmap and issue accompanying incentive policies to ensure sustainable development for current emission reduction goals.

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